# EXHIBIT D

# Variable Precision Floating Point Modules

## Contents


- Introduction
- Floating Point Modules
- Download Area
- Other Information


## Introduction

We have developed a library of fully parameterized hardware modules for variable precision floating-point arithmetic. The library includes modules for format control, arithmetic operators and conversion to and from any fixed-point format. All the modules have been implemented in VHDL and designed to run on different FPGA devices. They have been tested on reconfigurable computing engines from Annapolis Microsystems.

An important feature of these modules is that denormalize, and normalize/round are decoupled from the arithmetic operations. This gives the designer full control over where and when to normalize floating point calculations, and results in savings of area in their hardware implementation. The currently implemented arithmetic operators are floating point add/sub and floating point multiply. Floating Point Divide, Square Root, and Multiply Accumulate (MAC) are planned in the near future.

Please let us know if you are using the library by sending email to Prof. Leeser. We would also like to receive bug reports. We will do our best to keep the library up to date.

Back to Top

## Floating Point Modules

**Fixed-point to floating-point conversion (unsigned)**

**Fixed-point to floating-point conversion (signed)**

**Floating-point to fixed-point conversion (unsigned)**

**Floating-point to fixed-point conversion (signed)**

**Floating-point adder/subtracter**

**Floating-point multiplier**

**Floating-point round and normalizer**

Click here for a graph of the dependences for each of the modules in the library.

Back to Top

# Download Area

All the original library modules can be downloaded here. (Created on June, 2002)

All the revised library modules can be downloaded here. (Last updated on Jan, 2003)

Modules updated are:

| | |
|---|---|
| Updated Modules | parameterized_mux<br>parameterized_adder<br>parameterized_comparator<br>parameterized_variable_shifter_row<br>shift_adjust |
| Removed Modules | onc_bit_comparator<br>mux2<br>shift_control |
| Added Modules | parameterized_shifter |

To use the modules, first unzip the zip file to some directory. In this directory, there are two subdirectories, one is named *library_modules*, which contains the modules for format control, operators and conversion to and from any fixed-point format. The other is named *floatlib*; it contains all the necessary sub-modules. The dependencies of these modules can be found by click the hyperlink on the left side. To simulate, first compile all the vhd files in directory *floatlib*, then compile the module you want simulate in the *library_modules*, configure library modules according to the dependencies.

Here is an example of building a single precision IEEE floating point library using our modules.

If you have any questions or problems using the library, please contact Haiqian Yu

**Back to Top**

# Other Information

**Publications:**

Pavle Belanovic and Miriam Leeser, *A Library of Parameterized Floating Point Modules and Their Use*. 12th International Conference on Field Programmable Logic and Application. September, 2002.

Pavle Belanovic *Library of Parameterized Hardware Modules for Floating-Point Arithmetic with An Example Application* M.S. Thesis, Dept of Electrical and Computer Engineering, Northeastern University, June 2002

**People**:

**Faculty:** Dr. Miriam Leeser

**Graduate Students:** Pavle Belanovic, Haiqian Yu

**Institutions**:

Rapid Prototyping Lab

**Terms:**



Back to Top

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**Created and maintained by Haiqian Yu**

**Rapid Prototyping Lab, ECE Department, Northeastern University Last revised: March 06, 2003.**